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SURVEY OF ELECTROEXPLOSIVE DEVICES

Clarkson College of Technology
Potsdam, NY 13676

January 1977

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Final Report

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This research was sponsored by the Defense Nuclear Agency under Subtask R99QAXEB0971, Work Unit 52, Subtask Title: Theoretical and Experimental EMP Vulnerability.

Prepared for

Director

DEFENSE NUCLEAR AGENCY

Washington, DC 20305

AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base, NM 87117

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This final report was prepared by Clarkson College of Technology, Potsdam, New York under Procurement Directive 76-268, Job Order WDNE1406, with the Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico. Sgt Bruce Huehn (DYX) was the Laboratory Project Officer-in-Charge. Dr. D. C. Wunsch was the AFWL Task Officer for the Technical Directive which accomplished this work.

This research was sponsored by the Defense Nuclear Agency under Subtask R99QAXEB0971, Work Unit 52, Subtask Title: Theoretical and Experimental EMP Vulnerability. The DNA Subtask Managers were Major W. Dean, Major Adams, and Capt Wilson.

This technical report has been reviewed and is approved for publication.

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Electroexplosive Devices
Hot Bridge Wire
Exploding Bridge Wire
Carbon Bridge Wire
Electromagnetic Pulse
Susceptibility

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The object of this report is to explore all possible sources regarding electro-explosive devices including visits to principal laboratories that have conducted tests on these devices to ascertain if further testing is necessary to determine their susceptability to electromagnetic pulses.

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INTRODUCTION

GENERAL INFORMATION

The types of electrically initiated electroexplosive devices are; the hot wire (or hot bridge), exploding bridgewire (EBW), and carbon bridge. These devices are used to detonate warheads, initiate rocket motors, separate stages, ejection of bombs and rockets. Some devices are initiated mechanically, especially for crew ejection systems.

The most common electroexplosive device (EED) is the hot bridge type (BW). Therefore, most of the information contained in the report will be confined to bridgewire (BW) type EED's. This device primarily consists of resistance wire, primary explosive, secondary explosive, container, and lead wires. The resistance wire or bridgewire may be a Platinum-Iridium wire or Evanohm wire. The dimensions are in the order of 0.001" in diameter by 0.06" long. Evanohm, manufactured by the Wilbur B. Driver Company, is a specially alloyed and processed nickel-chrome metal with the following typical analysis: Ni 74.50%, Cr 20.00%, Al 2.75%, and Cu 2.75%. Although it does not readily soft solder, Evanohm may be welded or brazed successfully. Its maximum recommended working temperature is 300°C and the temperature coefficient of resistance can be maintained at 20ppm per °C over a temperature range of minus 50°C to plus 100°C.

The resistance wire is heated by virtue of current through it. When the wire reaches a sufficiently high temperature (approximately 300°C), the primary explosive deflagrates but within a few milliseconds or less detonates. This shock wave energy causes detonation of the secondary explosive.

Lead Azide and Lead styphnate are the most commonly used primary explosives. They are sensitive explosives with explosion temperatures of 340°C and 282°C respectively. Secondary explosives are less sensitive. They will not detonate when subjected to a hot wire, friction, spark or flame as will a primary explosive. Several of the secondary explosives commonly used are: PETN (Pentaerythritol tetranitrate), TNT (Trinitrotoluene), RDX (Cyclothimethylenetrinitromine), and TETRYL (Trinithophenylemethylnithamine).[1]

Further important properties of primary and secondary explosives disclosed by a differential thermal analysis indicates that virtually no important phase changes occur to primary explosives as temperature is increased to detonation. However, secondary explosives usually undergo significant phase changes. This is evident in that primary explosives generally proceed rapidly to detonation as heat is applied slowly whereas secondary explosives often pass through a melting or decomposition phase after which initiation is much more difficult. Therefore, dudding of primary explosives is far less likely than dudding of secondary explosives.[1]

Undesirable Modes of Ignition

Undesirable modes of ignition which may be primarily attributed to physical deficiencies of the EED construction, primary explosives, and conductive mix or metal additives to the explosives are: radio frequency (RF) enery captured by the leads, which heats the bridgewire to its ignition temperature, high potential differences between BW or lead and the case, sufficient to cause voltage breakdown and a resultant arc initiation, conduction of current from the bridgewire or header posts directly through the explosive mixture, and cook off from heating of the case or the dielectric plug in which the lead wires are formed to ignition temperature.[1]

Nondestructive Tests and Their Significance

Considering the undesirable modes of ignition stated above, it is recommended that 100% nondestructive screening tests be performed to weed out faulty units. The following tests are recommended:

1. Transient Pulse Test

   This test requires that the bridgewire form one arm of a wheatstone bridge. A step current waveform is applied to the bridge circuit. This pulse must be small enough to avoid firing or degrading of the EED, however large enough for meaningful electrothermal response. The resistance wire used for the bridge has a particular temperature coefficient of resistance and hence, as it heats, unbalance of the bridge occurs, which results in an error voltage to develop across the bridgewire terminals. This error voltage, which can be related to the temperature rise in the bridgewire, may be observed on an oscilloscope display. The instrumentation also allows a qualitative measurement of thermal conductance, thermal time constant, and cold bridgewire resistance.[3] Abnormalities of the oscilloscope trace may result from poor welds, BW movement, and air gaps between BW and explosive.

2. Thermal Time Constant

It is important to evaluate the thermal time constants of EED's, particularly when considering pulsed RF fields, for example, a single radar pulse may not deliver sufficient energy to fire an EED. However, subsequent pulses may induce thermal stacking such that firing could occur. This depends on the thermal time constant of the EED and the radar pulse repetition frequency (PRF). That is, if the PRF $<< \frac{1}{5\tau}$ where τ is the thermal time constant, then thermal stacking will not occur. Obviously, total time exposure to the radar field is important.

The relationships for heating and cooling thermal time constants are given below:[1]

$$\tau = \frac{C_p}{\gamma - I^2 R_o \alpha}$$ Heating thermal time constant

$$\tau' = \frac{C_p}{\gamma}$$ Cooling thermal time constant

where C_p = heat capacity of a lumped composite system watt sec/°C

γ = heat loss watt/°C

R_o = resistance of (BW) at 25°C

α = temperature coefficient of resistance of the BW material

I = current through the BW in amperes

Example - For the Mk 1 Mod 0 squib C_p = 2.4μ watt sec/°C,

γ = 600μW/°C, τ' = 4MS[1]

3. Electrothermal Follow

A 10Hz sinusoidal current is applied to a self-balancing wheatstone bridge which permits the EED to be taken through a thermal cycle. The temperature excursion can be controlled and the BW error signal may be displayed on an oscilloscope. Heating curves shown in Figure 1 are typical waveforms of three groups of EED's. Groups A and B were both single BW designs, from different manufacturers; group C was a dual BW design. The waveforms illustrate how BW heating unbalances the wheatstone bridge in a cyclic manner producing a lissajous figure.[4] This test is qualitative in nature and is best applied as a gross inspection tool.[3]

Note, group C displayed nonohmic nonlinear responses indicative of poor BW welds and variations in intimacy of contact between the bridgewire and pyrotechnic mixture.[5]

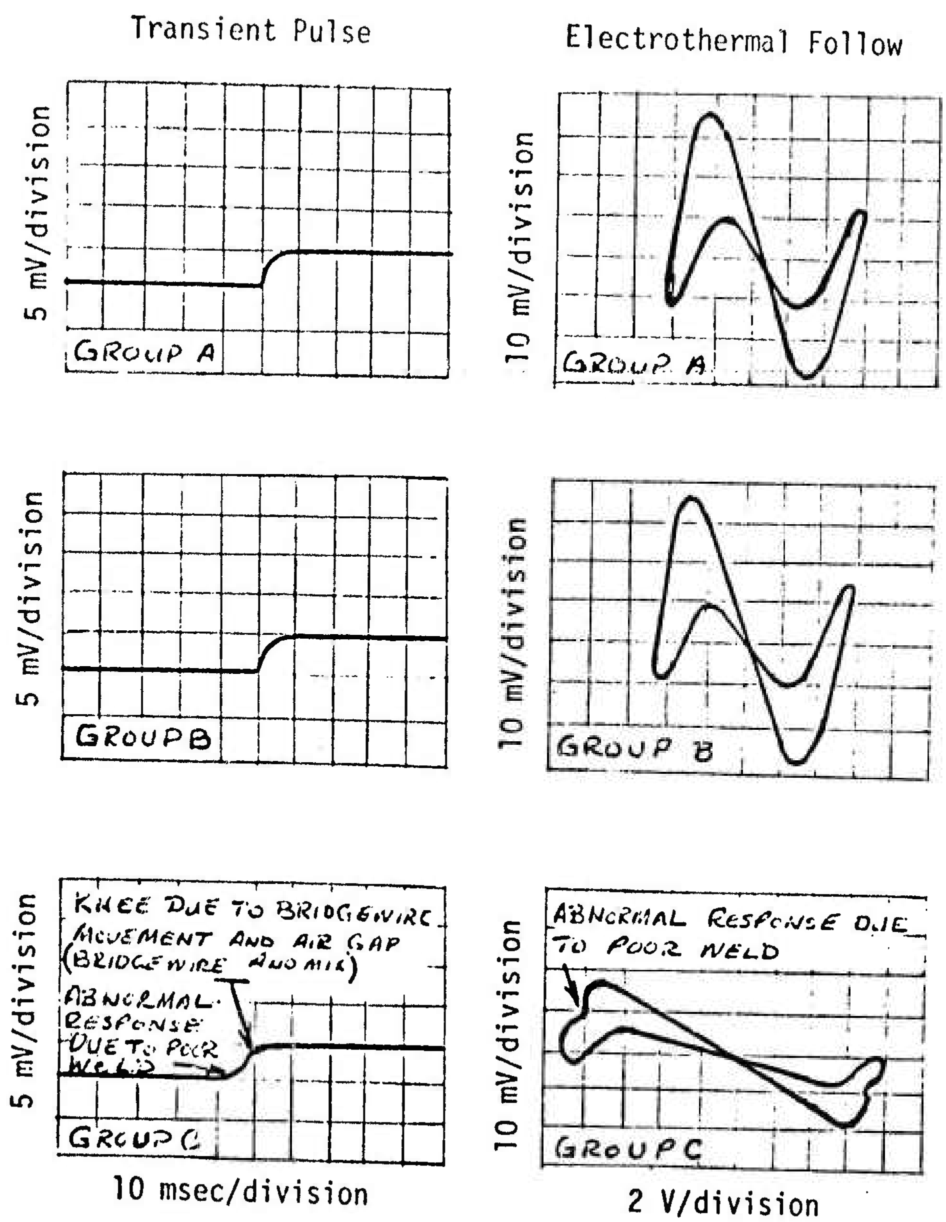

Fig. 1 Heating curves produced during nondestructive tests of EED's.

2 4. <u>Recommended Environmental Screening Tests</u>

The nondestructive tests discussed above should be taken preceding and following each environmental test listed below:

a. Vibration test consisting of 6 sinusoidal vibration scans starting at 10gs with 10g intervals from 8 to 2000Hz applied to each of 3 orthogonal axes of the EED's.

b. Thermal shock test from +121°C to -196°C.

c. Hot and cold storage test at +121°C and -196°C for one week.[3]

Destructive Tests and Their Significance

Sensitivity and output of EED's may be determined by destructive tests. Instrumentation to initiate and deliver energy in an impulsive manner by controlling pulse width and amplitude, has been developed. Calculation of the total energy delivered and a visual display of the bridgewire behavior is accomplished by monitoring the pulse. The power supply generating the impulsive waveform is referred to as the half-sine-wave pulser.[6] A measure of the output may be obtained by using a calibrated aluminum honeycomb element crushed in a controlled manner, and by measuring the reduction in the length of the element.[7]

Other pertinent information determined by destructive tests are energy to adiabatically fire, time to bridgewire burnout, time to end-seal rupture, total work, and peak pressure.[3]

Summary of Tests Performed by LASL[1]

Direct current no-fire, mean fire, and all fire levels can be used qualitatively as estimates for RF sensitivities. In general, RF power required for firing, at the most susceptible frequencies exceed those of the corresponding DC levels.[1]

EED Types	No. Tested	DC No-fire Current (amps)	DC Median firing (amps)	DC all-fire current (amps)
1. MK 1 Mod 0	55	0.23	0.259	0.292
2. MK 2 Mod 0	30	1.36	1.44	1.52
3. MK 71	30	0.094	0.144	0.220
4. GG20D3	30	0.101	0.127	0.159
5. E-81	30	0.310	0.386	0.481
6. E-108	30	0.442	0.533	0.644
7. E-106	30	0.352	0.383	0.416
8. SEM	30	0.147	0.169	0.195
9. ARD-863-1	5	0.350	0.850	1.60
10. MK 125 Mod 0	5	1.27	1.57	1.88
11. CCU-1/B	30	1.42	1.67	1.91
12. OM 351C	30	0.416	0.467	0.524
13. NEI-11	30	1.00 (1.46)*	1.55	1.65
14. BA79E0	30	0.135	0.163	0.198
15. D74B1	30	0.197	0.217	0.238
16. T24E1	30	0.050(.067)*	0.080	0.095

The no-fire and all-fire values were extrapolated from data to 0.995 reliability (±2.58σ) and 95% confidence level.

The no-fire criteria used is DC one ampere/one watt for 5 minutes.

*Dudding likely if the lower value is exceeded.

For types ARD-863-1 and MK 125 Mod 0, the electrical characteristics were taken for T.O. 11-1-34 and NWL report respectively.

EED Types	Normal BW Res. (ohms)	DC no-fire power (watts) = I_{nf}^2R	**SS CW field	Equivalent power density watts/m^2
1. MK 1 Mod 0	1 ± 0.1	0.53	20v/m	1
2. MK 2 Mod 0	0.18 ± 0.02	0.333	100v/m	26.5
3. MK 71	5 ± 1.7	0.044	30v/m	2.5
4. GG20D3	7 ± 0.5	0.120	30v/m	2.5
5. E-81	1.2 ± 0.3	0.062	50v/m	6.6
6. E-108	0.48 ± 0.14	0.094	50v/m	6.6
7. E-106	0.44 ± 0.26	0.070	130v/m	45
8. SEM	2 ± 0.12	0.043	-	-
9. ARD-863-1	1.25 ± 0.3	2.218	170v/m	75
10. MK 125 Mod 0	1.1 ± 0.1	1.774	130v/m	45
11. CCU-1/B	1.1 ± 0.1	0.122	250v/m	160
12. OM 351C	1 ± 0.2	0.173	60v/m	10
13. NEI-11	1 ± 0.1	1.000	160v/m	70
14. BA79E0	4.5 ± 0.5	0.73	27v/m	1.9
15. D74B1	1.8 ± 0.5	0.082	30v/m	2.5
16. T24E1	3.5 ± 1.5	0.008	20v/m	1

**Assuming perfect dipole coupling and 50 ohm source impedance, the EED's near its mean firing level in a steady state field.

EED Types	Most susceptible frequency (MHz)	Type of BW (Bridgewire)
1. MK 1 Mod 0	550	Platinum-Iridium 0.001 Dia by 0.60" long
2. MK 2 Mod 0	450	Platinum-Iridium (80-20) .002" by 0.60" long
3. MK 71	750	Nominal resistance 4-6$^{\Omega}$
4. GG20D3	400 to 500	-
5. E-81	400 to 500	-
6. E-108	420	-

EED Types	Most susceptible frequency (MHz)	Type of BW (Bridgewire)
7. E-106	1000	-
8. SEM	-	-
9. ARD-863-1	1250	Center pin to case ground
10. MK 125 Mod 0	850	Center pin to case ground
11. CCU-1/B	1400	Sigmund Cohn No. 479 (C.P. to case ground)
12. OM 351C	500	Nichrome per QQ-R-175 Comp D
13. NEI-11	400 to 500	Karma Wire
14. BA79E0	400	-
15. D74B1	450	-
16. T24E1	550	-

EED Types	Thermal Time Constant (MS at no fire current level)	Dielectric with standing voltage
1. MK 1 Mod 0	4	3000VDC for 5 sec.
2. MK 2 Mod 0	10	3000VDC for 5 sec.
3. MK 71	1	1800V for 5 sec. fired at 2000V
4. GG20D3	4	2000V for 5 sec. fired at 2100V
5. E-81	7.5	3000V for 5 sec. fired at 3100V
6. E-108	9.0	3000V for 5 sec.
7. E-106	4.0	3100V for 5 sec.
8. SEM	4.0	2000V for 5 sec. fired at 2500V
9. ARD-863-1	10.0	-
10. MK 125 Mod 0	18.5	-
11. CCU-1/B	13	-
12. OM 351C	5	3100V for 5 sec.
13. NEI-11	5	2000V for 5 sec. fired at 2800V

EED Types	Thermal Time Constant (MS at no fire current level)	Dielectric with standing voltage
14. BA79E0	4	3100V for 5 sec.
15. D74B1	3	2300V for 5 sec.
16. T24E1	2	2000V for 5 sec.

EED Types	Electrostatic Discharge Sensitivity (500PF capacitor charged to 25KV, 5000 ohms series resistor)
1. MK 1 Mod 0	pin to pin: no fires, pin to case: no fires (based on 5 samples)
2. MK 2 Mod 0	pin to pin: no fires, pin to case: 2 fires (based on 5 samples)
3. MK 71	pin to pin: 3 fired at 5KV, 1 at 10KV, 1 at 25KV (all fired) pin to case: with 5000^{Ω} series resistance, all 5 fired at 5KV
4. GG20D3	pin to Pin: 10KV 500^{Ω}, 4 fired; 25KV 500, 1 fired; 20KV 5000^{Ω}, 1 fired; 25KV $5K^{\Omega}$, 4 no fired. pin to case: 5KV, 5000^{Ω}, 5 of 5 fired
5. E-81	pin to pin: no fires, pin to case: no fires
6. E-108	pin to Pin: no fires, pin to case: no fires
7. E-106	pin to pin: no fires, pin to case: no fires
8. SEM	pin to pin: no fires, pin to case: no fires
9. ARD-863-1	pin to pin: no fires, pin to case: not applicable (one pin is case ground)
10. MK 125 Mod 0	pin to pin: no fires, pin to case: not applicable (one pin is case ground)
11. CCU-1/B	pin to pin: no fires, pin to case: not applicable (one pin is case ground)
12. OM 351C	pin to pin: no fires, pin to case: 1 of 5 fired

EED Types	Electrostatic Discharge Sensitivity (500PF capacitor charged to 25KV 5000 ohms series resistor)
13. NEI-11	
14. BA79E0	pin to pin: no fires, pin to case: 1 of 5 fired
15. D74B1	pin to pin: no fires, pin to case: 5 of 5 fired
16. T24E1	pin to Pin: 2 of 3 fired at 4KV; 1 fired at 6KV, pin to case: 3 of 3 fired at 3KV

EED Types	Recommendation Regarding Use
1. MK 1 Mod 0	Not recommended because of its low firing current.
2. MK 2 Mod 0	Limited operational use, does not meet 1 watt-5 min. no fire criteria.
3. MK 71	Not recommended, the electrostatic discharge sensitivity, overall RF, and DC sensitivity are unacceptable, a suitable substitute should be developed.
4. GG20D3	Not recommended because of its relatively low initiation current, low RF power requirements, and general electrostatic sensitivity.
5. E-81	Not recommended because of its relatively low initiation current and relatively low RF power initiation. Use E-107 1.6A/1W as a substitute.
6. E-108	Not recommended because of its low RF power initiation threshold. Use E-107.
7. E-106	Not recommended because of its low initiation current and relatively low power initiation threshold. Use E-107.
8. SEM	The SEM is not an effective stray monitor device, it is too insensitive. In addition, at frequencies above 1000MHz,

EED Types	Recommendation Regarding Use
8. SEM (continued)	it is nearly impossible to fire this device with RF powers of up to 5 watts. Investigation is underway to develop better stray energy monitor devices, project 56/0, task 03 for ADC (ENVCC) Wright Patterson AFB, Ohio.
9. ARD-863-1	Not recommended because it does not meet the desired 1A/1W no-fire requirements desired by the USAF and relatively low RF power-firing threshold acceptable replacement cartridges are available (see USAF T.O. 11-1-34).
10. MK 125 Mod 0	Recommended. The MK 124 Mod 0 and MK 125 Mod 0 were developed as substitutes for ARD 440-1 and ARD 863-1 (see T.O. 11-1-34). To maintain safety levels use shielded twisted pair leads to the cartridge. Although the cartridge has a case ground, single line firing circuits with chassis ground returns should not be used.
11. CCU-1/B	Recommended because they are highly resistant to accidential initiation.
12. OM 351C	Not recommended because it does not meet the 1A/1W no-fire requirement desired by the USAF, and its relatively low RF power firing requirements.
13. NEI-11	Recommended because it satisfactorily meets 1A/1W, 5 minute no-fire criteria but duds when 1.3A is applied. Therefore, the recommended firing current is 2 amperes minimum.
14. BA79E0	Not recommended because of its relatively low DC and RF power firing thresholds.
15. D74B1	Not recommended because of its relatively low DC and RF firing thresholds. Also the electrostatic discharge sensitivity is unacceptable.
16. T24E1	Not recommended. The T24E1 was the most sensitive device tested. It should be replaced with the AGM-65A which is more resistant to Electromagnetic radiation (EMR).

Recommendations and Conclusions

1. The EED's of the hot bridge variety are generic in nature, sufficient tests and test procedures have been devised. However, retrofitting of sensitive devices used in systems is recommended, which should be apparent from the data summarized in this report.

2. The test procedures recommended are those outlined in Technical Report ASD-TR-73-70, pp. 115-130 which are included as Appendix I of this report.

   In addition, it is recommended the acceptance tests, Table II p. 23, should include the transient pulse test and the electrothermal follow test described on pages 4, 5, 6, and 7 of this report. The acceptance tests measurements should precede and follow each environmental test listed on page 8 .

3. It is recommended that the RF impedance measurements are performed with a Hewlett Packard 8542A automatic network analyzer or equivalent as outlined in Technical Report ASD-TR-23-70, p. 25 to p. 32 which is included as Appendix II of this report.

4. Further consideration should be given to improvements in hot wire electroexplosive devices discussed in detail in Technical Report LA-5373-MS, by Richard M. Joppa. Particularly the feasibility of utilizing only secondary explosives thereby increasing safety margins in high RF and electrostatic environments.

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APPENDIX I

Suggested Procurement Specification for Electroexplosive Device

1. Scope

1.1. This specification covers the electrical ignition parameters of an electroexplosive ordnance device. The specification of the various parameters and requirement of performance tests are intended to lessen the possibilities of accidental initiation of the device, but to have it function reliably when the proper electrical firing energy is applied to it. This specification applies to the ordnance portion of the device only. Tests for initial qualification of the device are contained in Table I; Tables II and III contain required tests for subsequent lot acceptance testing, following qualification of the basic device.

2. Applicable Documents

2.1. The following documents, of the latest issue in effect, form a part of this specification to the extent specified.

Specifications

MIL-Q-9858 Quality Program Requirements

MIL-I-23659 Initiators, Electric, Design and Evaluation of

Standards

MIL-STD-202 Test Methods for Electronic and Electrical Component Parts

MIL-STD-1512 (USAF) Electroexplosive Subsystems, Electrically Initiated, Design Requirements and Test Methods

Regulations

49 CFR Interstate Commerce Commission Rules and Regulations Sec. 71-78 for the Transportation of Explosives and Other Dangerous Articles

3. Requirements

3.1. General. The electroexplosive devices (EEDs) shall meet the requirements specified in Tables I, II and III.

3.2. Quality Program Requirements. The manufacturer shall establish a quality program in accordance with MIL-Q-9858.

3.3. Data Requirements. Information for the Technical Data Record Sheet, a copy of which is supplied with this specification, is to be complete.

3.4. Marking. Each EED shall be marked or tagged with the manufacturer's name or trademark, manufacturer's part number and/or model number, the lot number, and the date of manufacture (acceptance inspection).

3.5. Dimensions. The dimensions of each EED shall conform to the specified drawing.

3.6. Cleanliness. The exterior of the EED shall be clean and free from soldering flux, oil, grease, explosive matter, and other foreign matter. There shall be no visible blemishes on the surface of the actuators.

3.7. DC Resistance. When measured as prescribed in 4.6.3, the dc resistance shall be within specified limits.

3.8. Transient Current Test. When subjected to the transient current test as specified in 4.6.4, no EED shall show trace abnormalities. Any abnormal EED shall be discarded and it shall be replaced by a new device.

3.9. DC Function Time. When tested at 10 different current levels, the corresponding function times shall be recorded as specified in 4.6.5. This data will serve to establish interval estimates for the dc sensitivity requirement of 3.10.

3.10. DC Sensitivity Test. As specified in 4.6.6, this test consists of a Bruceton method firing to establish median firing current value and to estimate no-fire and all-fire current levels.

3.11. DC No-Fire Sensitivity. As specified in 4.6.7, this test certifies the no-fire current level predicted in 3.10 (at 94.5% confidence) and, in conjunction with 3.12, verifies the one ampere/one watt 5 minute no-fire, no-dudding requirement.

3.12. DC All-Fire Sensitivity. As specified in 4.6.8, this test confirms the predicted all-fire point (at 94.5% confidence) from 3.10.

3.13. Dielectric Withstanding Voltage. When the EEDs are tested as specified in 4.6.9, there shall be no flashover, breakdown, firing, or other physical damage or deterioration.

3.14. Electrostatic Discharge Sensitivity. When tested as specified in 4.6.10, the EEDs shall not fire.

3.15. Thermal Time Constant Determination. The thermal time constant of the EED shall be determined as specified in 4.6.11.

3.16. RF Impedance Measurement. As specified in 4.6.12, the rf pin-to-pin and pin-to-case impedance shall be measured and recorded.

3.17. RF Sensitivity. As specified in 4.6.13, the EEDs shall be subjected to direct radio frequency stimuli and the rf sensitivity determined. The rf impedance data from 3.16 will be used as a guide in frequency selection.

3.18. Environmental Tests. If the EED electrical parameters are to be determined under various environmental conditions (temperature, shock, vibration, altitude, humidity, etc.) additional requirements, test procedures, and test specimens should be provided by the procuring activity. MIL-I-23659B (AS) may be utilized in structuring the desired environmental requirements and tests.

4. Quality Assurance Provisions

4.1. Classification of Tests. The inspection and testing of electroexplosive devices shall be classified as follows:

a. Qualification Tests (see 4.2)

b. Acceptance Tests (see 4.3)

4.1.1. Additional Tests. Nothing shall prevent the manufacturer from taking such additional samples and performing such additional tests as he may deem necessary or desirable to assure conformance to the requirements of this specification. Additional tests may be conducted by the USAF to verify data submitted by the manufacturer.

4.2. Qualification Tests. Qualification tests are tests performed at the discretion of the USAF to determine whether the components meet the requirements of this specification.

4.2.1. Qualification Test Sample and Routine. The total test sample, consisting of 182 specimens, shall be subjected to the Group I tests and shall then be divided into Test Groups II through IV. The number of specimens in each test group and the order of testing shall be as indicated in Table I. If additional environmental tests are desired, the total test sample and group allocations should be increased accordingly.

4.3. Acceptance Tests. Unless otherwise specified in the Purchase Order, the manufacturer is responsible for performing all the acceptance tests specified in 4.3.1 and 4.3.2.

4.3.1. Screening Tests. The acceptance tests specified in Table II shall be performed in the order shown on a 100% screening basis. Defectives found during the 100% screening tests shall be eliminated from the lot and shall not be shipped.

4.3.2. Sampling Tests. The acceptance tests specified in Table III shall be performed in the order shown on a sampling basis. Unless otherwise specified in the Purchase Order, the 50 specimens that have been subjected to these destructive sampling tests shall not be included with the quantity shipped in fulfillment of the Purchase Order.

4.3.2.1. Sample size. Each sample to be tested shall consist of 50 specimens selected at random and without regard to quality from each lot of 55 units or less.

4.3.2.2. Production Lot. The manufactured lot shall consist of a sufficient number of units to supply both the test sample and the quantity ordered. Each lot shall be derived from the same manufacturer and shall consist only of units manufactured on one production line under essentially similar conditions and, so far as practicable, at essentially the same time.

4.3.2.3. Lot Acceptability. The lot acceptability shall be determined in accordance with the acceptance number specified in Table III. If the number of failures exceeds the specified acceptance number, the entire lot shall be rejected.

4.3.3. Test Equipment and Facilities. The manufacturer may use his own or any other laboratory facilities approved by the USAF. The quality of the facilities and the accuracy of the equipment shall be sufficient to assure performance of the acceptance tests within the specified requirements.

Table I. Qualification Tests

Test Group	Number of Specimens	Test	Reference Paragraph Req.	Reference Paragraph Test
I	182	Visual Inspection, Dimension Check	3.5, 3.6	4.6.2
		DC Resistance	3.7	4.6.3
		Transient Current Test	3.8	4.6.4
II	10	DC Function Time Test	3.9	4.6.5
	50	DC Sensitivity (Mean Firing Level)	3.10	4.6.6
	5	DC No-Fire Sensitivity	3.11	4.6.7a
	10	DC No-Fire Sensitivity	3.11	4.6.7b
	10	DC All-Fire Sensitivity	3.12	4.6.8
III	5	Dielectric Withstanding Voltage Test	3.13	4.6.9
	5	Electrostatic Discharge Sensitivity	3.14	4.6.10
	2	Thermal Time Constant Determination	3.15	4.6.11
IV	5	RF Impedance Measurement	3.16	4.6.12
	80	RF Sensitivity	3.17	4.6.13
V		Environmental Tests as Desired		

Table II. Acceptance Tests (100 Percent Screening)

Number of Specimens	Test	Reference Paragraph Req.	Test
All	Visual Inspection	3.5	4.6.2
	DC Resistance	3.7	4.6.3
	Transient Current Test	3.8	4.6.4

Table III. Acceptance Tests (Sampling Basis)

Sample Size	Test	Reference Paragraph		Acceptance Number
		Req.	Test	
10	DC No-Fire Sensitivity	3.11	4.6.7b	0
10	DC All-Fire Sensitivity	3.12	4.6.8	10
20	RF Sensitivity	3.17	4.6.13	0
5	Dielectric Withstanding Voltage	3.13	4.6.9	0
5	Electrostatic Discharge	3.14	4.6.10	0

4.4. Certification. The manufacturer shall certify with each shipment that the EEDs have been subjected to the specified acceptance tests and have met the requirements.

4.5. Data Submittal. The manufacturer shall supply complete drawings to the USAF. A detailed description of the materials used in the construction of the EEDs shall be included in the manufacturer's drawings or shall be submitted separately. All data required by the EXPLOSIVE COMPONENT TECHNICAL DATA RECORD will be supplied.

P/N ______________________
Contractor

EXPLOSIVE COMPONENT TECHNICAL DATA RECORD

Ws__________ System Designation ____________________

1. ____

____

2. Federal Stock Number (if available) ________________________

____

3. Contractor (Supplier to Air Force) ________________________

   a. Part No. Drawing ________________________ (Contractor)

   b. Spec. No. ______________________________

4. Source/Vendor and Address ______________________________

____

   a. Part No. Drawing ______________________ (Manufacturer)

5. Function/Used on Drawing ______________________________

____

6. Hazard Classification

   a. Contractor Recommended Q-D Class ______________________
   (Per AFM 127-100)

   b. Contractor Recommended Compatibility Group ______________
   (Per AFM 127-100)

   c. Contractor Recommended Fire Symbol ____________________
   (Per AFM 127-100)

   d. DoT Class ____
   (Per Bu of Exp or T.C.G. Tariff 15)

   e. DoT Shipping Name ___________________________________

f. Fuze

(1) Time

(2) Mechanical

(3) V.T.

(4) Chemical

7. How shipped: Shipping Container Drawing No. if available

____
(Wood, Steel, Box, Crate, Drum, Skidded, etc.)

a. Qty. Items per Inner Shipping Container ______________

b. Qty. per Outer Shipping Container (If Applicable) ________

8. Size of Unpackaged Component (Inches) ______________

9. Weight of Component (less Package) ______________

10. Explosive, Pyrotechnic, or Propellant Composition and Makeup of Part

a. Formulation — Percent, Quantity, or Ft

Ignition (primary): ________ ______________

Booster (secondary): ________ ______________

Other: ________ ______________

b. Net Explosive Weight/Part or Device ________ (pounds)

c. Makeup of Assembly (Quantity and Type or Model)

Squib ______________

Detonator ______________

Delay ______________

Other ______________

d. Does ignition charge contain metal additive?

e. Is conductive mix present? If so, in which part of explosive device? ______________________

What is conductivity of mix (mhos/cm)? ____________

11. How Initiated (circle one)

a. Electric		c. Percussion

b. Stab		d. Delay

12. Electrical Characteristics:

a. Max No Fire (Current) ________Amps______Watts______Time

b. Min All Fire (Current)________Amps______Watts______Time

c. Maximum Test Current ________Amps for______Time

d. Mean Firing Current ________Amps

e. Mean Firing Energy ________Watt-seconds (Joules)

f. Bridgewire Resistance ________ohms

Bridgewire Material ______________________

Bridgewire Temperature Coefficient of Resistance ________

____

g. Part Receptacle Mates with________Plug

h. Pin Data______________Firing Circuit______________

____

(Notes: Show per numbers or letters. Resistance [Min____Max] values as measured at receptacle pins.)

13. Hazard Classification in Accordance with TO 11A-1-47 was accomplished by ____________________ (state whether by testing or comparative analysis).

14. Personnel Hazard ____

____

15. Additional Remarks ____

____

16. Storage Limits ____

a. Storage Temperature Limits ________ to ______________ °F

b. Storage Humidity Limits __________ to ______________ RH

17. Test Document ____

18. The following documents will accompany these technical data (all documents will be submitted in triplicate unless otherwise indicated)

a. For item 13 above: Report Form No. 1, Hazard & Stability Test required for DoT classification, dated 1 May 1962 (see TO 11A-1-47) or background data package used to establish hazard classification by comparative analysis. Seventeen copies per data record.

b. Detail drawings of component showing dimensions, installation adaptions, explosive constituents, and electrical schematic where applicable. Reduction to 11 x 17 or 8-1/2 x 11 inches is preferred.

c. Descriptive drawing of storage or shipping container.

d. Bureau of Explosives of DoT correspondence assigning approved DoT class and shipping name.

e. Component Specifications.

19. Bridgewire thermal time constant (at fire current rating)

____

20. Dielectric Withstanding voltage rating ______________ volts.

21. Electrostatic discharge rating ______________ volts based on discharge from 500 pf capacitor in series with 5000 ohms.

22. RF impedance data

pin-to-pin Smith Chart attached?

pin-to-case Smith Chart attached?

resistance versus frequency?

23. RF sensitivity data:

Frequency	Power to fire (watts)	Modes (p-p or p-c)

24. Known pulse sensitivities (p-p, p-c):

25. Function time versus current

Is plot of function time versus current on LOG-LOG plot attached?

26. General: Are there special features in the explosive portion of this device worthy of note? (Thin film bridge, arc-resistant construction, only secondary explosives, bridgewire pin-case ground, etc).

4.6. Methods of Examination and Test.

4.6.1. Standard Test Conditions. Unless otherwise specified, all measurements and tests shall be performed under the following ambient conditions:

Temperature	25° ± 5°C
Pressure	30 ± 2 inches of mercury
Humidity	75% maximum

Test equipment shall be attached to the EED lead wires at a distance of approximately 0.3 inch from the actuator case.

4.6.2. Visual Inspection. The EEDs shall be inspected to verify that the physical dimensions and marking conform to the applicable requirements. The EEDs shall also be inspected for cleanliness and for surface blemishes. (See 3.5 and 3.6.)

4.6.3. DC Resistance. The EEDs shall be tested in accordance with Method 201 of MIL-STD-1512. The mean, standard deviation, and 3 sigma deviation resistances shall be computed. In addition, pin-to-case resistances will be measured (on all EEDs where pin-to-case resistance differs from pin-to-pin resistance). Pin-to-case resistance shall be 5 megohms or greater. (See 3.7.)

4.6.4. Transient Current Test. The EED shall form one of the legs of a wheatstone bridge circuit with an applied square wave current pulse as described in NASA TR 32-1494 "Nondestructive testing of insensitive electroexplosive devices by transient techniques," Jet Propulsion Laboratory, July 1970 or in IEEE Transactions on Instrumentation & Measurement, "Electrothermal Measurements of Bridgewires Used in Electroexplosive Devices," June 1965. A peak current not to exceed 0.4 of the no-fire value shall be applied. The period of the ON current pulse shall be 50 milliseconds, with 50 millisecond cooling periods between pulses. The bridge shall be approximately balanced by adjustment of the variable resistor in the bridge leg opposite the EED. The resulting oscilloscope pattern should display a smooth trace. Irregular traces during the heating portion of the cycle are indications of bridgewire-explosive deficiencies and shall be cause for rejection of the unit being tested. (See 3.8.)

4.6.5. DC Function Time Test. This is a dc test of the normal firing mode (pin-to-pin) of an electroexplosive device. Test data will be plotted on LOG-LOG paper with constant current value as abcissa, function time as ordinate. Function time will be taken as that time when the explosive reaction is observed to start as indicated by a rapid increase in the EED pin-to-pin voltage (caused by chemical heating of the bridgewire) when observed on an oscilloscope photograph. Applied constant current levels should begin near the expected mean firing point and be varied with subsequent test items as necessary to get a representative spread of points on the LOG-LOG plot between expected no-fire and all-fire current values. (See 3.9.)

4.6.6. DC Sensitivity (mean Firing Level) Test. This test shall be conducted using a constant current source in the standard Bruceton manner (for procedure see NAVORD Report No. 2101, or Applied Mathematics Panel, National Defense Research Committee AMP Report No. 101.R SRG-P No. 40 "Statistical Analysis for a New Procedure in Sensitivity Experiments" or NASA-TM-X-64491, "A Guide for the Application of the Bruceton Method to Electroexplosive Devices," F. M. Speed, Sept. 1, 1966). Use the data from 4.6.5 to estimate stimulus increments. Compute the median firing current level (m), the no-fire level ($m-2.58\sigma$), and the all-fire level ($m+2.58\sigma$) to a reliability of 0.995 at a 95% confidence level unless other reliability and confidence levels are specified. Using the no-fire units (which will be approximately one-half the sample, for a properly conducted test), conduct another Bruceton test with small increments around the median. Compare the "no-fires" median with the original median to see if preconditioning appreciably changes the median firing value. (see 3.10.) The median current level should be indicated on the function time-current plot generated in 4.6.5.

5

4.6.7. DC No-Fire Sensitivity. (a) The first 5 EEDs of the sample shall be tested in accordance with method 202 of MIL-STD-1512. In the event that the no-fire current rating is less than 1 A, apply the no-fire current for a minimum of five minutes. If the device fires, the no-fire level computed in test 4.6.6 is too high (a common shortcoming of extrapolating Bruceton data to extremes of the distribution) and a lower value should be tried. A 10% lower value should be selected and the process repeated until a satisfactory no-fire current level which can be endured for 5 minutes is selected.

When the true no-fire 5 minute level is selected, the remainder of the first 5 units should be so exposed. These units should then be subjected to the all-fire current level (with firing anticipated) to ensure that the no-fire 5 minute test was not a cause for failure or dudding (see 3.11). (b) The objective of this test is to verify the 94.5% confidence level placed on the no-fire current initially estimated in 4.6.6 and refined in 4.6.7. The "true" no-fire current level selected in 4.6.7a should be applied successively to 10 EEDs for 5 minutes each and none should fire, fail or dud. As in 4.6.7a, if a firing or failure occurs, the no-fire rating should be adjusted downward until 10 units can be successively tested without a failure. The no-fire level should be indicated on the function time plot generated in test 4.6.5.

4.6.8. DC All-Fire Sensitivity. The purpose of this test is to verify the 94.5% confidence level at the all-fire current stimulus predicted by the Bruceton test of 4.6.6. Successively subject each of the 10 EED specimens to the all-fire current level. If all 10 fire, the test is complete. If any fail to fire, the all-fire current level must be revised upward until 10 EEDs fire successively. An average function time for the all-fire current level should be computed. This point (and associated all-fire current) should be indicated on the function-time-current plot generated in test 4.6.5 (see 3.12).

4.6.9. Dielectric Withstanding Voltage. The EEDs shall be tested in accordance with Method 301 of MIL-STD-202. The following details shall apply (see 3.13).

(a) Magnitude of test voltage: 2000 ± 100 volts dc

(b) Duration of test voltage: not less than 5 seconds

(c) Points of application of test voltage: Between the wire leads shorted together and the body of the EED.

4.6.10. Electrostatic Discharge Test. The EEDs shall be tested in accordance with Method 205 MIL-STD-1512, except that only 5 specimens are required and no statistical methods are required. Firing of any device in any mode in this test constitutes failure. The 5 units should each be tested pin-to-case and then re-tested pin-to-pin and bridgewire-to-bridgewire (if applicable). Points of application of test voltage in the pin-to-case test are between the wire leads shorted together and the body of the EED. Normal firing with all-fire current level applied should then be confirmed (see 3.14).

4.6.11. Determination of Thermal Time Constant. Refer to test 4.6.4. The same equipment and technique is to be utilized except that the peak current will be equal to the no-fire current level determined in 4.6.7b and resistors R_2, R_1, and capacitance C_2 will be adjusted as described in the referenced articles.

$$\text{Record } \tau \text{ (the heating time constant)} = \left(\frac{R_2}{R_1 + R_2}\right)(R_2C_2)$$

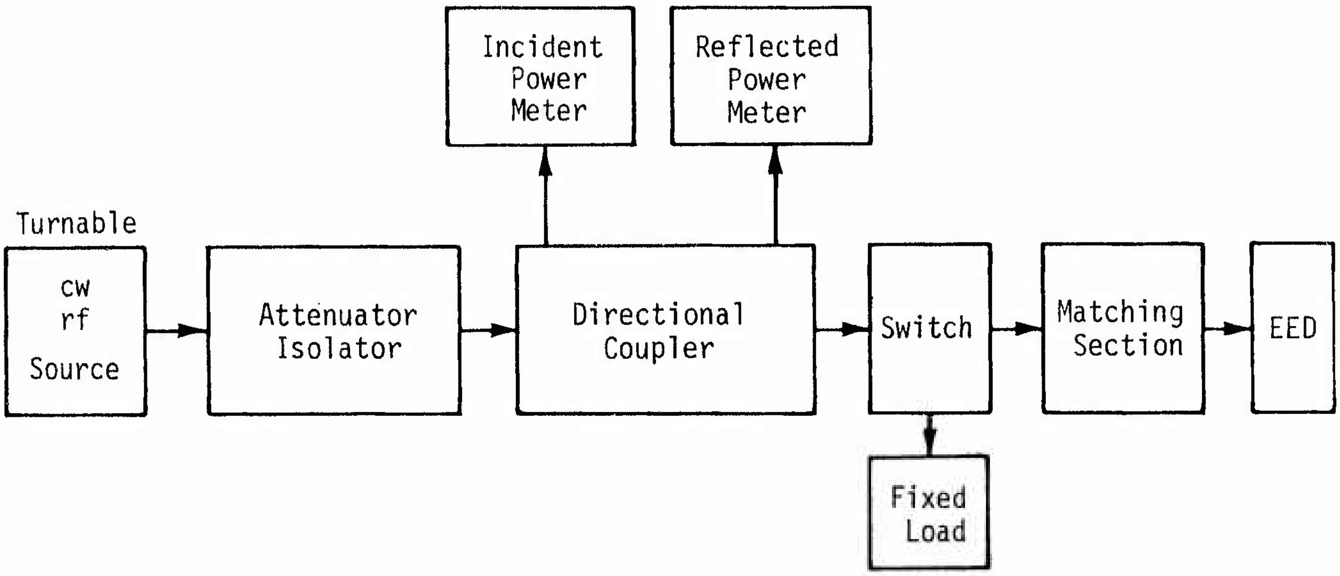
$$\text{and } \tau \text{ (the cooling time constant)} = R_2C_2$$

Note that a bridgewire with a non-zero temperature coefficient of resistance (α) is required for this test. The square wave generator frequency should not exceed $1/10\tau$ (see 3.15).

4.6.12. RF Impedance Measurement. The pin-to-pin and pin-to-case (between one lead and the body of the EED, with the other lead floating) impedance of the EED will be measured as in method 204 of MIL-STD-1512.

Leads should be kept as short as possible (0.3 inch or shorter). Measurement on a Hewlett-Packard 8542A automatic network analyzer or similar equipment is preferred. Frequencies between 100 MHz and 8 GHz shall be used unless otherwise specified. At least 100 MHz increments from 100 MHz to 1 GHz and 200 MHz increments from 1 GHz to 8 GHz are required. Plot the results for each EED on a standard Smith Chart. Plot the mean values separately on a standard Smith Chart. Separates plots of reactance and vector impedance are not required. Plot the mean resistance (real part of impedance) in terms of VSWR (referred to 50 ohms) on semi-log paper versus frequency. This plot will be used in selecting test frequencies for 4.6.13 (see 3.16).

4.6.13. RF Sensitivity. Test the rf cw sensitivity of EEDs in accordance with method 207 MIL-STD-1512, except that only 80 (single bridgewire) EEDs and 4 frequencies are required. For the pin-to-pin mode, select 4 frequencies from the resistance versus frequency plot which show the lowest VSWR and which give a reasonable cross-section of test results across the frequency regions of interest. Some minor frequency tuning about these frequencies should be accomplished to achieve the best match. (Note: those frequencies chosen will normally be where the Smith Chart plot crosses the R= 50 ohm contour.) For the pin-to-case mode, test at those 4 frequencies selected for the pin-to-pin mode. The pin-to-case connections are to be between one bridgewire and the body of the EED, with the other lead floating. No statistical analysis is required. If the EED proves to be highly rf sensitive (when net rf power is compared with dc mean power), contact the procurement agency for further instructions. For acceptance testing, only the single most sensitive frequencies in pin-to-case and pin-to-pin mode need be tested. A test equipment setup similar to that shown in Figure 4.6.13-1 (below) is required.



5. Preparation for Delivery

5.1. Preservation and Packaging. The actuators shall be preserved and packaged in accordance with the requirements of the code of Federal Regulations, 49 CFR, sections 71 through 78.

5.2. Package Marking. The actuator containers shall be marked in accordance with the requirements with the Code of Federal Regulations, 49 CFR, sections 71 through 78. In addition, the containers shall be marked with the manufacturer's name, or trademark, the manufacturer's part number, and the lot number.

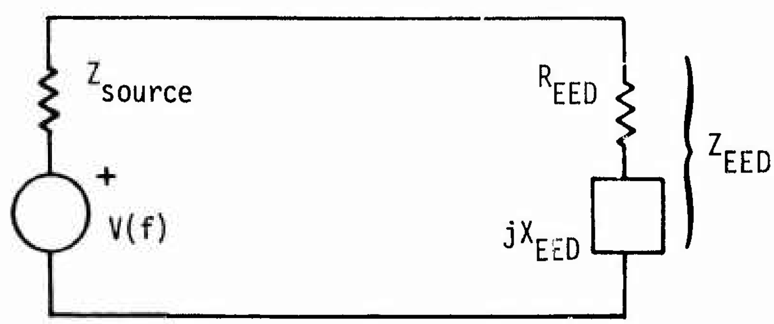
APPENDIX II

FREQUENCY CONSIDERATIONS

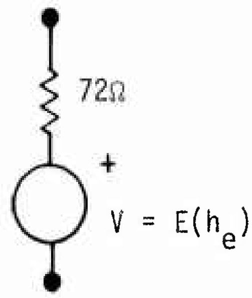
1. General

In considering the response of EEDs to rf at various frequencies, an essential piece of information is the impedance (or admittance) characteristics of the EED as a function of frequency. Without such information one can hardly predict response of the device at various frequencies. Stating the problem in a different fashion, EEDs may be test-fired at various frequencies but such test data gives characteristics only of the test item. An analytical basis is the foundation for any test program if the results are to be extended to other items.

The following circuit model is presented to illustrate the significance of EED frequency information:



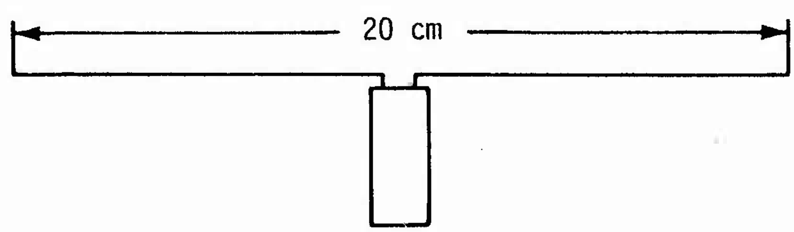
The well-known maximum power transfer condition for the above circuit occurs when $Z_{source} = Z^{*}_{EED}$ where * indicates conjugate. For example, if the source impedance at some frequency were 3 ohms resistance and 10 ohms inductive resistance (3 + j10), then maximum power would be dissipated in the resistive part of the EED if and only if the EED impedance were 3 - j10 (3 ohms resistance and 10 ohms capacitive reactance). To further illustrate the applicability of this model to the physical situation, a half-wave dipole antenna may be modeled as follows (at exactly the resonant frequency):



At frequency of resonance, the antenna has a source resistance of 72 ohms (resistive) and an induced voltage (assuming maximum ideal coupling) which is proportional to the strength of the sinusoidally-varying electric field E, multiplied by the effective height of the antenna, which is $\frac{\lambda}{\pi}$ meters for a dipole.

In an electric field of 200 V/m and a frequency of 750 MHz, this antenna has a theoretical maximum induced voltage of $\frac{(200)(300)}{\pi\ (750)} = 25.5$ volts. (Note that the induced voltage increases as frequency decreases.)

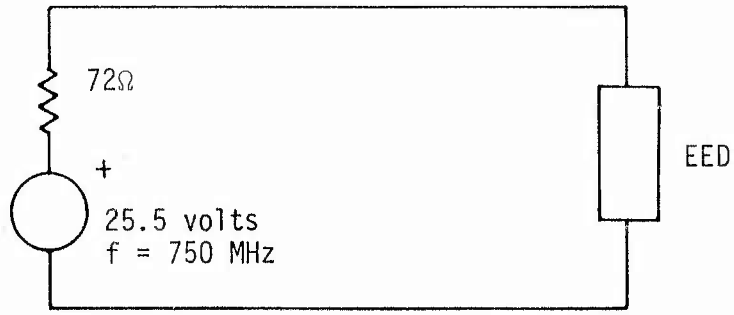
If the leads from a Mk 2 EED were each 10 cm in length and were formed into a dipole:



and were exposed to an electric field of 200 V/m and 750 MHz, would the EED fire?

$$\lambda/2 = 20 \text{ cm} = 0.2 \text{ m},\ \lambda = 0.4\text{m},\ f = \frac{300}{0.4} = 750 \text{ MHz}$$

The leads form a half-wave dipole resonant at 750 MHz, so the circuit model is:



If the EED impedance were 72 ohms resistive, 2.26 W could be delivered to the EED and firing would be likely (assuming all the available power was delivered to the bridgewire). (An average dc power of approximately 0.4 W is required for firing.) If, however, the EED impedance were 1 + j75 ohms, the power delivered to the EED resistance would be only 60 mW and firing would not occur. Thus EED impedance information is essential.

The need for nondestructive impedance characterization of EEDs (both pin-to-pin and pin-to-case) was recognized by LASL engineers before work on this project began, and action was taken to procure a Hewlett-Packard Model 8542A Automatic Network Analyzer to provide the needed measurements. Although it is highly useful in other measurement applications, the HP8542A was primarily committed to the EED program. Manpower savings, as well as accuracy, repeatability, and nondestructive characterization were prime requisites in the decision to purchase this piece of equipment.

Output data is presented in four forms from the LASL HP8542A:

- Teletype page printer output
- Punched paper tape
- Oscilloscope tube display, which may be photographed
- Automatic x-y plotter, which reproduces the oscilloscope display.

The frequency range covered by the HP8542A is from 100 MHz to 18 GHz. Measurements are, of course, limited by fixture accuracy. As a result, EED measurements were typically limited to an upper frequency of 8 GHz. Some of the rf safety-containment fixtures developed for EED characterization use with the HP8542A.

DISTRIBUTION LIST

No. cys	
1	Cdr, Picatinny Arsenal (Tech Lib), Dover, NJ 07801
1	Cdr, NESC (Tech Lib), Wash, DC 20360
1	Maxwell Lab (Tech Lib), 9244 Balboa Ave, San Diego, CA 92123
1	DCEC (R124C), 1860 Wiehle Ave, Reston, VA 22090
12	DDC (TCA), Cameron Sta, Alexandria, VA 22314
1	Cdr, DESC (ECS/Tech Lib), 1507 Wilmington Pike, Dayton, OH 45401
3	DDR&E (Dep Dir, Strat/Sp Sys; DAD SK, G. Barse; DD/S&SS), Wash, DC 20301
2	Cdr, FC DNA (FCSM-A; FCPR), Stop 44
1	JSTPS (Tech Lib), Offutt AFB, NE 68113
1	Dir, NSA (Tech Lib), Ft Meade, MD 20755
1	Wpn Sys Eval Gp (Tech Lib), 400 A-N Dr, Arlington, VA 22202
2	Dir, BMDATC (Tech Lib; SSC-TEN, N. Hust), POB 1500, Huntsville, AL 35807
1	Ch, R&D, Dept Army (DARD-DDM-N, LtC Gonce), Wash, DC 20310
1	Cdr, USAMC, RSIC (Ch, Doc Sec), Redstone Arsenal, AL 35809
1	Cdr, SCA (ACCX-SAT-EMP), Ft Huachuca, AZ 85613

No. cys	
1	Cdr, SSSAC (Ch, Act Div), POB 631, Langdon, ND 58249
1	Cdr, USA-A (NBC DIV AFZT-PTS-C, Maj Dean), APO Seattle, WA 98749
1	Cdr, USAEC (AMSEL-TL-IR, Dr. Hunter), Ft Monmouth, NJ 07703
1	Cdr, ASD (Tech Lib), WPAFB, OH 45433
1	Sim Phys (J. Uglum), POB 974, Boxborough, MA 07120
1	CICCADC (DCS/C&E, CESA), Ent AFB, CO 80912
1	Cdr, DCA, Nat Mil Cmd Sys Spt Ctr (Tech Lib), Wash, DC 20305
1	Dir, DIA (Tech Lib), Wash, DC 20301
	Dir, DNA, Wash, DC 20305
2	(STTL)
3	(STSI; STVL; DDST, P. Haas)
4	(RAEV)
1	Intsvc Nuc Wpn Sch (Doc Cont), Stop 9
1	Ch, FC DNA, LLL (L-395), POB 808, Livermore, CA 94550
1	Ofc JCS (Tech Lib), Wash, DC 20301
1	Asst CS, Com/Elc (CEED-7, W. Heath), Dept Army, Wash, DC 20314
1	CE, Dept Army (DAEN-MCE-D, Mr. McCauley), Wash, DC 20310
1	Dept Army, FESA (Ch, R&T Div), Ft Belvoir, VA 22060

No. cys	
	Cdr, Diamond Lab (AMXDO), 2800 Powder Mill Rd, Adelphi, MD 20783
5	(EM, A. Renner; J. Klebers; R. Bostak; R. Wong; R. Gray)
2	(RB, J. Miletta; E. Conrad)
2	(NP, S. Marcus; F. Wimenitz)
3	(RBF, J. Tompkins; RC, Dr. Oswald; TI)
1	Cdr, TRASANA (SSEA-EAB, F. Winans), WSMR, White Sands, NM 88002
1	Cdr, USACSC (Tech Lib), Ft Belvoir, VA 22060
2	Ch, USACSA (S. Krevsky, DD Eng; Tech Lib), Ft Monmouth, NJ 07703
1	Cdr, USAMER&DC (Tech Lib), Ft Belvoir, VA 22060
1	Cdr, USANA (Tech Lib), Ft Bliss, TX 79916
2	Ch, USAN&CSGp (MOSG-NO, Maj Winslow; Tech Lib), Bldg 2073, No Area, Ft Belvoir, VA 22060
1	Cdr, WSMR (STEWS-TE-NT, M. Squires), White Sands, NM 88002
1	OIC, CEL, NCBC (Tech Lib), Pt Hueneme, CA 93041
1	CO, NAD (Tech Lib), Crane, IN 47522
1	Cdr, NELC (Tech Lib), San Diego, CA 92152
1	Supt, NPS (2124), Monterey, CA 93940
5	Cdr, NSWC (431, Dr. Malloy; E. Dean; M. Petree; 130-215, E. Rathbun; Tech Lib/Info Svc Div), White Oak, Silver Spring, MD 20910
1	Cdr, NWC (753), China Lake, CA 93555

No. cys	
1	CO, NWEF (ADS), Stop 40
1	Cdr, ASD (YHEX, Maj Leverette), WPAFB, OH 45433
1	AFATL (DLOSL), Eglin AFB, FL 32542
1	Cdr, FTD (PQAL), WPAFB: OH 45433
1	SAMSO (MN), Norton AFB, CA 92409
2	CINCSAC (NRI/STINFO; XPFS, Maj Stephan), Offutt AFB, NE 68113
2	USAEC NVL (Capt Parker; Tech Lib), Ft Belvoir, VA 22060
	Cdr, USAMC, Redstone Arsenal, AL 35809
2	(AMSMI/RGP, H. Green; V. Rowe)
3	(AMCPM/MD, SAM-D Proj Mgr; AMCPN/HA, HAWK Proj Mgr; Tech Lib)
1	Proj Mgr, USATDS (Tech Lib, Ft Monmouth, NJ 07703
1	Cdr, USAT&EC (Tech Lib), Abdn Pvg Gnd, MD 21005
1	Ch, NOps, Dept Navy (Tech Lib), Wash, DC 20350
1	Cdr, NASC (Tech Lib), Wash, DC 20360
1	Cdr, NCC (Tech Lib), 4401 Massachusetts Av NW, Wash, DC 20390
1	Cdr, NOSC (ORD-034C, S. Barnham), Wash, DC 20360
9	Dir, NRL (4004, Dr. Brancato; 6603F, R. Statler; 2627, D. Folen; 6633, J. Ritter; Tech Lib; 7706, J. Boris; 7701, J. Brown; 464, R. Joiner; 7770, D. Levine), Wash, DC 20375
	Cdr, NSWC, Dahlgren, VA 22448
2	(W. H. Holt)
2	(FUR, Dr. Amadori; Tech Lib)

No. cys	
1	Dir, SSPO, Dept Navy (Tech Lib), Wash, DC 20376
1	ARL (Tech Lib), WPAFB, OH 45433
1	Cdt, AFFDL (R. Beavin), WPAFB, OH 45433
1	CS, USAF (RDQSM), Wash, DC 20330
1	Cdr, RADC (Tech Lib), Griffiss AFB, NY 13441
2	LASL (Rpt Lib; K. Riepe, L-1), POB 1663, Los Alamos, NM 87544
1	Sandia Lab (K. Mitchell, 8157), POB 969, Livermore, CA 94550
6	ESD (DCD/SATIN IV; DCKE, L. Staples; YWES; XRE-Surv; MCAE, LtC Sparks; XRP, Maj Gringrich), Hanscom AFB, MA 01730
7	Sandia Lab (3141; E. Hariman; A. Limieux; 5223, C. Vittitoe; 2126, J. Cooper; 1935, J. Gover; 9353, R. Parker), Stop 40
2	CIA (RD/SI, Rm 5G48, Hq Bldg; Tech Lib), Wash, DC 20505
1	NASA-Marshall SFC (ASTR-MTD, A. Coleman, Bldg 4476), Huntsville, AL 35812
1	Aerojet El-Sys (T. Hanscome, 8170/D6711), POB 296, Azusa, CA 91702
1	Avco, GPG (Rsch Lib, A830/7201), 201 Lowell St, Wilmington, MA 01887
1	BMI (Tech Lib), 505 King Ave, Columbus, OH 43201
1	BPC (Proj Mgr, Gov Proj, H. Dietze), POB 60860, LA, CA 90060

No. cys	
1	Bendix Aerosp Sys Div (R. Pizarek), 3300 Plymouth Rd, Ann Arbor, MI 48107
1	Bendix Nav/Cont Div (E. Lademann), Teterboro, NJ 07608
1	BA/H (R. Chrisner), 106 Apple St, New Shrewsbury, NJ 07724
3	BDM (D. Durgin; D. Alexander; Tech Lib), POB 8885, Sta C. Albuq, NM 87108
1	CSD Lab (Tech Lib), 68 Albany St, Cambridge, MA 02139
1	CEC (Tech Lib), 2630 Glendale/Milford Rd, Cincinnati, OH 45241
8	SAMSO (SKT, P. Stadler; RSP, LtC Gilbert; DYS, Maj Heilman; SZH, Maj Schneider; SKD; IND, I. Judy; DYJB, Capt Ingram; SZJ, Capt Dejonckheere), POB 92960, WWPC, LA, CA 90009
2	UCC, Holifield Nat Lab (Dr. D. Nelson; Tech Lib), POB X, Oak Ridge, TN 37830
1	UC, LLL (Tech Lib), POB 808, Livermore, CA 94550
1	Dept Commerce, NBS (J. French, Elc Tech Div), Wash, DC 20234
1	NASA-Lewis RC (Lib), 21000 Brookpark Rd, Cleveland, OH 44135
13	Aerosp Corp (Lib; S. Bower; Dr. Pearlston, A2/220; R. Murtensen, Hard Reent Sys; J. Benveniste; Dr. Comisar; Dr. Reinheimer; I. Garfunkel, 115/2076; R. Crolius, A2/1027; N. Stockwell, N&E Stf; L. Aukerman, 120/2841; V. Josephson, D&S Dir; D. McPherson, Tech Surv Dir), POB 92957, LA, CA 90009
1	Bell Aerosp (Tech Lib), POB 1, Buffalo, NY 14240

No. cys	
1	Bell Tel Lab (Tech Lib), Mountain Ave, Murray Hill, NJ 07974
1	Bendix RLD (D. Niehaus, Mgr, Pgm Dev), Bendix Cen, Southfield, MI 48075
7	Boeing Co (R. Caldwell; D. Egelkrout; Lib; Dr. Dye, 2-6005, 45-21; H. Wicklein, 17-11; A. Lowrey, 2R-00; D. Kemle), POB 3707, Seattle, WA 98124
1	Brn Eng (Tech Lib), Cummings Rsch Pk, Huntsville, AL 35807
1	Burroughs Fed/Spec Sys (Tech Lib), Central Ave/Rte 252, Paoli, PA 29301
1	CRC (M. Lahr, Lib, 106-216), 5225 C Ave NE, Cedar Rapids, IA 52406
1	CSC (P. Carleston), POB 530, Falls Church, VA 22046
1	EG&G (Tech Lib), POB 10218, Albuq, NM 87114
2	FC&IC (D. Myers, 2-233; Tech Lib), 464 Ellis St, Mountain View, CA 94040
2	Franklin Inst (R. Thompson; Tech Lib), 20 St/Pkwy, Phila, PA 19103
1	Gen Dyn Corp, Elc Div (Tech Lib), POB 81127, San Diego, CA 92138
6	GE Co, Sp Div, VFSC (L. Chasen; J. Peden, CCF 8301; D. Tasca, 8301-C8; J. Spratt, M9549; J. Andrews, Rad Eff Lab; TIC), POB 8555, Phila, PA 19101
1	GE Co (B. Showalter, 160), POB 5000, Binghampton, NY 13902
1	GE Co (Tech Lib), POB 1122, Syracuse, NY 13201

No. cys	
1	GRC (Dr. Johnson), 1501 Wilson Blvd, Suite 700, Arlington, VA 22209
1	Goodyear Aerosp Corp (B. Manning), Litchfield Park, AZ 85340
1	GTE Sylv, ESGp (Tech Lib), 77 A St, Needham, MA 02194
1	Harris Semicond (Tech Lib), POB 883, Melbourne, FL 32901
2	Hercules Bacchus Plt (R. Woodruff, 100K-26-W; Tech Lib), POB 98, Magna, UT 84044
2	Honeywell Aerosp (H. Noble, Stf Eng, 725-5A; Tech Lib), 13350 US Hwy, St Petersburg, FL 33733
4	Hughes Acft, ASD (A1080, W. Scott; C624, E. Smith; A1080, H. Boyte; Tech Lib), POB 92919, LA, CA 90009
1	Dikewood (Tech Lib), 1009 Bradbury Dr SE, Univ Rsch Pk, Albuq, NM 87106
1	ELC Com (J. Daniel, 9), POB 12248, St Petersburg, FL 33733
2	Fairchild Ind, SFTC (Mgr, CD&S; Tech Lib), 20301 Century Blvd, Germantown, MD 20767
2	Garrett Corp (R. Weir, 93-9; Tech Lib), 9851 Sepulveda Blvd, LA, CA 90009
1	GE Co, Ord Sys (D. Corman, 2171), 100 Plastics Ave, Pittsfield, MA 01201
1	GE Co, RESD (Tech Lib), POB 7722, Phila, PA 19101
1	GE Co, AES (Tech Lib), French Rd, Utica, NY 13503
2	GE Co, TEMPO-Cen Adv Stud (Dr. Rutherford; DASIAC), PODwr QQ, Santa Barbara, CA 93102

No. cys	
1	GE Co, AEG-TIC (J. Ellerhorst, E2), Evendale Plt, Cincinnati, OH 45215
3	GRC (Dr. Hill; J. Ise; TIO), POB 3587, Santa Barbara, CA 93105
2	Grumman Aerosp Corp (J. Rogers, 533, Pt 35; Tech Lib), S. Oyster Bay Rd, Bethpage, NY 11714
1	GTE Sylv (Tech Lib), 189 B St, Needham Heights, MA 02194
2	Hazeltine Corp (M. Waite, TL; J. Colombo), Pulaski Rd, Green Lawn, NY 11740
2	Honeywell GAPD (Tech Lib; R. Johnson, A1391), 1625 Zarthan Ave, Minneapolis, MN 55416
1	Honeywell RC (Tech Lib), 2 Forbes Rd, Lexington, MA 02173
1	Hughes Acft, GSGp (Lib, 600, C-222), 1901 W. Malvern Ave, Fullerton, CA 92634
3	IITRI (I. Mindel; J. Bridges; Tech Lib), 10 W. 35 St, Chicago, IL 60616
6	Hughes Acft (K. Walker, D157; B. Campbell, 6-E110; W. McDowell, R&D; Dr. Binder, 6-D147; Dr. Singletary, D157; Tech Lib), Centinela/Teale Sts, Culver City, CA 90230
1	ITT (Tech Lib), 500 Washington Ave, Nutley, NJ 07110
1	ITT Cannon Elc (D. Shaff), 2801 Air Lane, Phoenix, AZ 85034
1	Litton Sys, Elc Tube Div (F. McCarthy), 1035 Westminster Dr, Williamsport, PA 17701
1	LTV Aerosp, VSD (TDC), POB 6267, Dallas, TX 75222
2	LTV Aerosp (T. Rozelle; Tech Lib), POB 909, Warren, MI 48090

No. cys	
1	MM Aerosp (Tech Lib), POB 5837, Orlando, FL 32805
2	McDon Doug (Dr. Ender, 313, 33; Tech Lib), POB 516, St Louis, MO 63166
1	McDon Doug (T. Lundregan), POB 1850, Albuq, NM 87103
1	MRC (Dr. Van Lint), 7650 Convoy Ct, San Diego, CA 92111
1	Mitre Corp (Tech Lib), POB 208, Bedford, MA 01730
1	Northrop Elc Div (Tech Lib), 1 Rsch Pk, Palos Verdes Peninsula, CA 90274
1	Northrop Elc Div (Tech Lib), 2301 W. 120 St, Hawthorne, CA 90250
1	Philco-Ford WDLD (Tech Lib), 3939 Fabian Way, Palo Alto, CA 94303
1	Pulsar Assoc (C. Jones), 7911 Herschel Ave, La Jolla, CA 92037
1	RAND Corp (Tech Lib), 1700 Main St, Santa Monica, CA 90406
1	IITRI, ECAC (Tech Lib), North Severn, Anapolis, MD 21402
1	IRT (Tech Lib), POB 81087, San Diego, CA 92138
1	IBM (Tech Lib), Rte 17C, Owego, NY 13827
1	Ion Phys (Tech Lib), S. Bedford St, Burlington, MA 01803
1	Kaman Sci (Tech Lib), POB 7463 Colorado Springs, CO 80933
2	Litton Sys, Data Sys (S. Sternbach; Tech Lib), 8000 Woodley Ave, Van Nuys, CA 91406
1	Lockheed M/S (TIC, G. Evans, 0-52-52), 3251 Hanover St, Palo Alto, CA 94304

No. cys	
2	MIT, Linc Lab (A. Stanley; L. Loughlin, Lib), POB 73, Lexington, MA 02173
1	MM Corp (Tech Lib), POB 179, Denver, CO 80201
1	McDon Doug (Tech Lib), 5301 Bolsa, Huntington Beach, CA 92647
1	MRC (Tech Lib), 325 State St, Santa Barbara, CA 93101
3	MRC (J. Hill; D. Merewether; Tech Lib), POB 8693, Sta C, Albuq, NM 87108
2	NAS (Dr. Shane, Nat Mtls Adv Bd; Tech Lib), 2101 Constitution Ave NW, Wash, DC 20418
1	Northrop R&TC (Tech Lib), 3401 W. Broadway, Hawthorne, CA 90250
1	Philco-Ford, A&COps, Aeronut (Tech Lib), Ford/Jamboree Rds, Newport Beach, CA 92663
2	Phys Int (Tech Lib; I. Smith), 2700 Merced St, San Leandro, CA 94577
1	R&D Assoc (Tech Lib), POB 3580, Santa Monica, CA 90403
1	Raytheon (Tech Lib), 528 Boston Post Rd, Sudbury, MA 01776
2	Raytheon (G. Joshi, Rad Sys Lab; Tech Lib), Hartwell Rd, Bedford, MA 01730
2	RCA G&S Sys, AED (Dr. Brucker; Tech Lib), POB 800, Locust Corner, Princeton, NJ 08540
5	Rockwell Int (G. Messenger, FB61; R. Hubbs, FB46; J. Bell, HA 10; J. Sexton, CA 31; Tech Lib), 3370 Miraloma Ave, Anaheim, CA 92803
1	Sperry Rand Gyro Mgt Div (Tech Lib), Marcus Ave, Great Neck, NY 11020

No. cys	
1	Sperry Rand Univac Def Sys (Tech Lib), POB 3525, MS 1931, St Paul, MN 55101
1	Texas Instru (Tech Lib), POB 5474, Dallas, TX 75222
1	BDM (Dr. Neighbors), 1920 Aline Ave, Vienna, VA 22180
12	TRW Sys Gp (A. Liebschutz, R1-2154; J. Lubell; A. Narevsky, R1-2144; R. Whitmer; R. Kingsland, R1-2154; R. Webb, R1-1071; F. Holmquist, R1-1070; Dr. Sussholtz; TIC, S1930; Dr. Jortner; W. Robinette), 1 Sp Pk, Redondo Beach, CA 90278
2	UAC Ham Std (R. Gignere; Tech Lib), Bradley Int Aprt, Windsor Locks, CT 06069
2	Westinghouse D&ESC (H. Kalapaca, 3525; Tech Lib), POB 1693, Fndsp Int Aprt, Baltimore, MD 21203
2	Cdr, USAR&DCtr (AMXRD-BVL, J. McNeilly; Tech Lib), Abdn Pvg Gnd, MD 21005
2	Cdr, USASA (IARD-T, Dr. Burkhardt; Tech Lib), 4000 Arlington Blvd, Arlington, VA 22212
1	Litton Sys G&CSD (Tech Lib), 5500 Canoga Ave, Woodland Hills, CA 91364
1	RCA G&C Sys, M&S Rad (Tech Lib), Marne Hwy/Borton Ldg, Moorestown, NJ 08057
1	RTI (Dr. M. Simons, Eng Div), POB 12194, Research Triangle Park, NC 27709
1	Rockwell Int (Tech Lib), 5701 W. Imperial Hwy, LA, CA 90009
1	Sci Appl (Tech Lib), POB 2351, La Jolla, CA 92038

No. cys	
2	Sperry Rand Flt Sys Div (Tech Lib; D. Schow, 104C), POB 21111, Phoenix, AZ 85036
1	SRI (Tech Lib), 306 Wynn NW, Huntsville, AL 35805
1	SRI (Tech Lib), 333 Ravenswood, Menlo Park, CA 94025
2	Texas Tech Univ (T. Simpson; Tech Lib), POB 5404, N Col Sta, Lubbock, TX 79417
2	TRW Semicond (R. Clarke, Tech Stf; Tech Lib), 14520 Aviation Blvd, Lawndale, CA 90260
1	TRW Sys Gp (Tech Lib), POB 1310, San Bernardino, CA 92402
2	TRW Sys Gp (D. Pubsley; Tech Lib), POB 368, Clearfield, UT 84015
1	UAC Norden (C. Corda), Helen St, Norwalk, CT 06851
1	Univ Denver CO Sem, DRI (Tech Lib), Univ Pk, Denver, CO 80210
1	Westinghouse RL (R. Wootton 301-2B3), Pittsburgh, PA 15235
1	Cdr, USAADC (Tech Lib), Ent AFB, CO 80912
2	Cdr, USAMC (A. Nichols, NDB 300, 95; Tech Lib), Picatinny Arsenal, Dover, NJ 07801
2	Ch, NR, Dept Navy (R. Joiner, 464; Tech Lib), Arlington, VA 22217
1	CO, Diamond Lab (Lib), Wash, DC 20438
1	Hq USAF (XOOWD), Wash, DC 20330
2	AFSC (DLCAW; XRP), Andrews AFB, Wash, DC 20334
1	USAFA (FJSRL, CC), CO 80840

No. cys	
1	AFIT (Tech Lib, 640, B), WPAFB, OH 45433
2	CO, USAEC (AMSEL-10-T; Tech Lib), Ft Monmouth, NJ 07703
1	Dir Ofc, LLL (TID), POB 808, Livermore, CA 94550
1	Hq USAF (RDQSM, 1D425), Wash DC 20330
1	Dir, BMD Prog Off, (Tech Lib) 1300 Wilson Blvd, Arlington, VA 22209
1	Westinghouse Elec Corp. Rsch labs (R. E. Wootton/301-2B3), Pittsburgh, PA 15235
1	Auburn Univ, Physics Dept. (Dr. P. P. Budenstein), Auburn, AL 36830
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1	(Dr. L. C. Martin/L-156)
1	(Dr. J. Candy/L-156)
1	State Univ of NY at Buffalo (Dr. J. J. Whalen), 4232 Ridge Lea Rd., Amherst, NY 14226
2	U.S. Army Msl Comd, G Directorate (D. Mathews/DRSMI/RGP), Redstone Arsenal, AL 35809
1	Clarkson College of Tech (Joseph Scaturro), Potsdam, NY 13676
1	Hq USAF, AFTAC, Patrick AFB, FL 32925
1	ADC (DPQY), Ent AFB, CO 80912
1	AUL (LDE), Maxwell AFB, AL 36112
	AFWL, KAFB, NM 87117
1	(HO, Dr. Minge)
2	(SUL)
15	(DYX, Dr. Wunsch)
1	(EL, J. Darrah)
1	(ELA, L. Eichwald)
1	(ELA, J. O'Donnel)
1	(ELA, R. Hays)
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